The VOrtex Ring Transit EXperiment (VORTEX) Data System and Flight Results

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Introduction

- **VORTEX was a student-run project organized by the University of Michigan Students for the Exploration and Development of Space (UMSEDS)**

- **VORTEX studied propagation of a vortex ring through a liquid–gas interface in microgravity**

- **G-093 flew on two Shuttle flights: STS-89 in January 1998 and on STS-88 in December 1999**
  - **VORTEX successful and collected scientific data on STS-88**

- **This paper overviews**
  - **Experiment sequence**
  - **Experiment controller and data acquisition system**
  - **Imaging system**

Scientific Objective

Interface

Vortex Ring

Γ

a
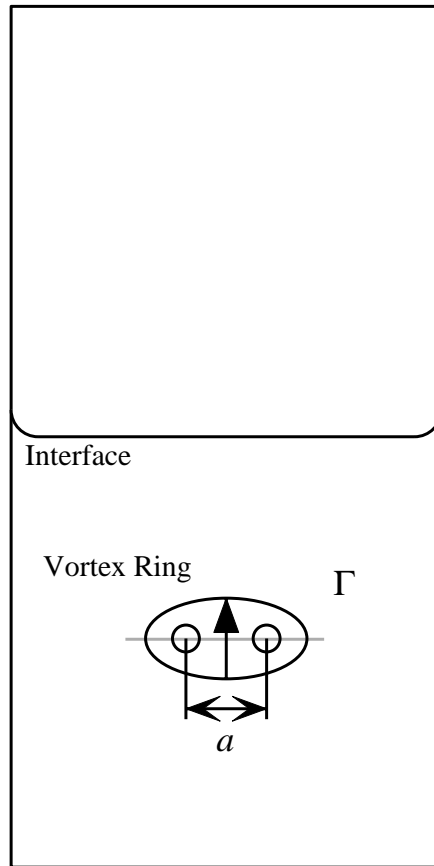
Before interaction
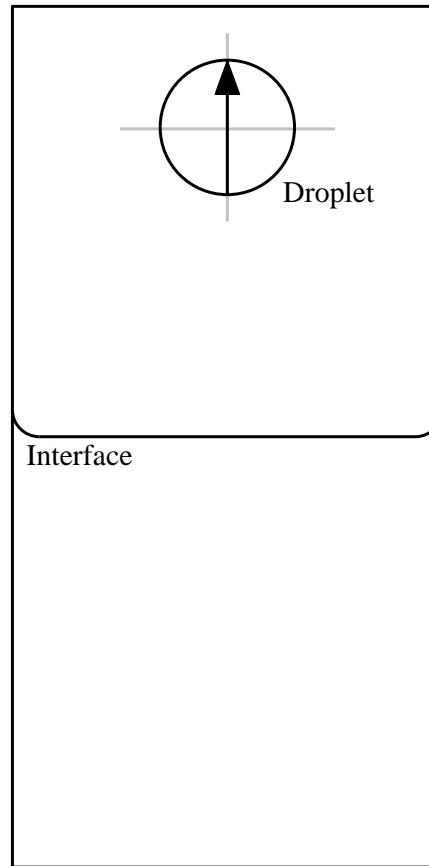
Droplet

Interface

After interaction

■ **Understand the propagation of vortex ring through liquid–gas interface in microgravity**

- • **VORTEX ring formed below interface propagates through interface**
- • **Collision with interface forms droplet**
- • **Vorticity distribution in vortex ring determines motion of liquid inside droplet**
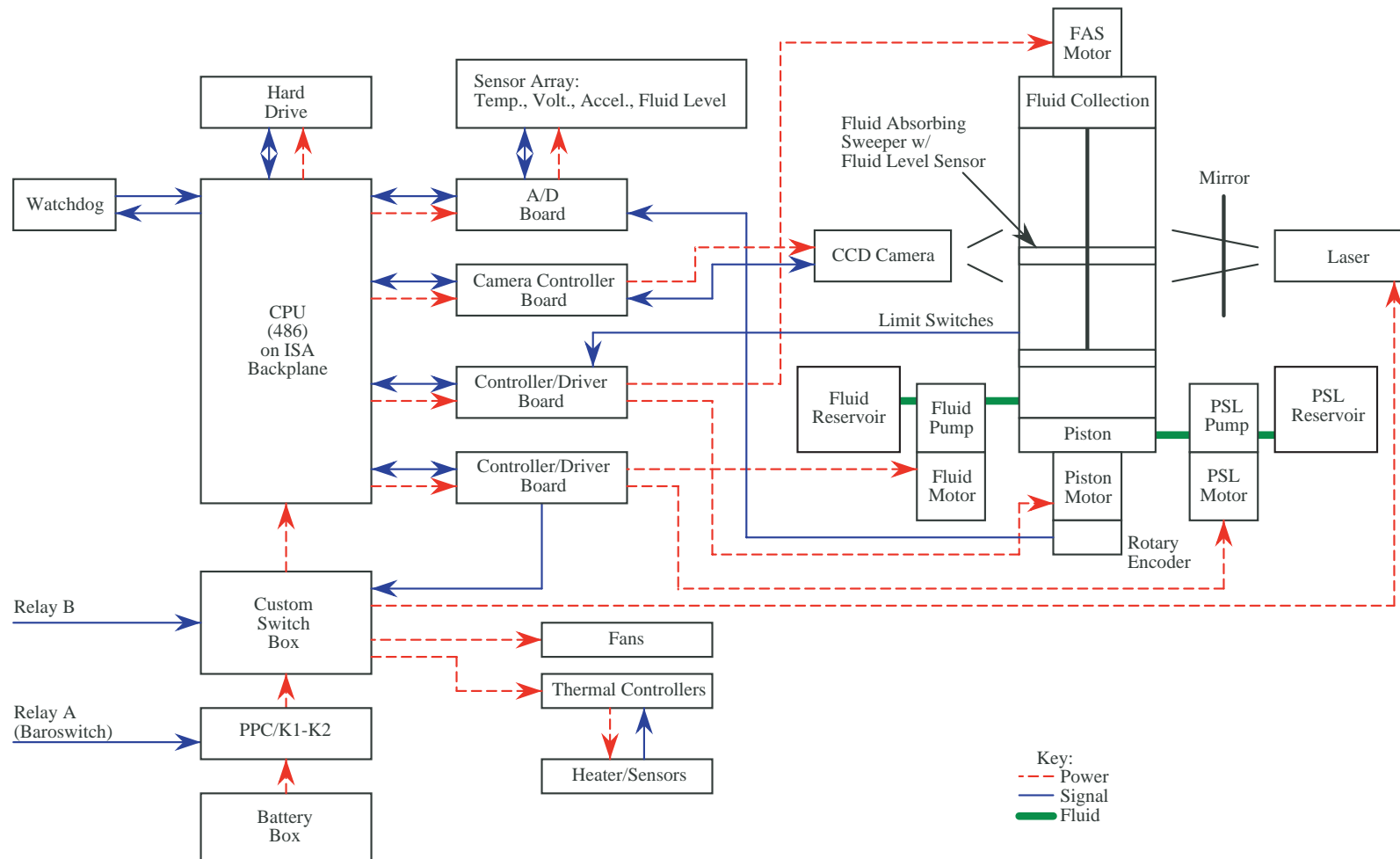
Theoretical Considerations

- **Collision and evolution of droplets depend on fluid inertia, viscosity, surface tension, and gravitational acceleration**

- **For a fixed liquid-gas interface the effect of gravity is characterized by the Bond number which depends only on $a\sqrt{g}$**

  - Atomization phenomena in 1 g with droplet size on the order of microns can be examined in microgravity (10^{-4} g) at a much larger scale

  - Bond number scaling: 1-cm-diam vortex ring in water propagating through the water-air interface at 10^{-4} g corresponds to a droplet size of 100 μm at 1 g

- **VORTEX examined interface breakup and droplet formation by a vortex ring at a**

  - Range of parameters relevant to fluid atomization processes

  - Resolution that cannot be obtained in ground-based experiments

Systems Diagram

Hard Drive

Sensor Array:
Temp., Volt., Accel., Fluid Level

FAS Motor

Fluid Collection

Fluid Absorbing Sweeper w/ Fluid Level Sensor

Mirror

Watchdog

A/D Board

CCD Camera

Laser

Camera Controller Board

CPU (486) on ISA Backplane

Limit Switches

Controller/Driver Board

Fluid Reservoir

Fluid Pump

PSL Pump

PSL Reservoir

Controller/Driver Board

Piston

Fluid Motor

Piston Motor

PSL Motor

Rotary Encoder

Relay B

Custom Switch Box

Fans

Relay A (Baroswitch)

PPC/K1-K2

Thermal Controllers

Heater/Sensors

Battery Box

Key:
- - - Power
—— Signal
━━ Fluid

Experiment Controller

- **Computer system controlled the experimental sequence of events and stored images and sensor data**

- **COTS hardware**
  - Modified industrial-grade case
  - 486 processor board on passive backplane
  - Camera board
  - Motor controller boards (2)
  - A/D acquisition board
  - Two 2-GB EIDE hard-drives

- **Experiment sequence controlled by dedicated program written in C++**
  - Board manufacturers provided linkable C/C++ subroutines

- **Watchdog would reset computer if not serviced every 5 minutes**

Sensors and Data Acquisition System

- **Sensor signals conditioned as necessary and sampled via A/D board**

- **Thermistors measured temperatures at 8 locations in payload**
  - Located on battery box, CPU, fluid reservoir, PSL reservoir, FTC, both hard-drives, and accelerometer

- **Accelerometer measured level of microgravity**
  - Three axes captured at gains of $\times 1$, $\times 10$, and $\times 100$

- **IR sensor on FAS measured fluid level in FTC**

- **Optical rotary encoder measured piston speed**
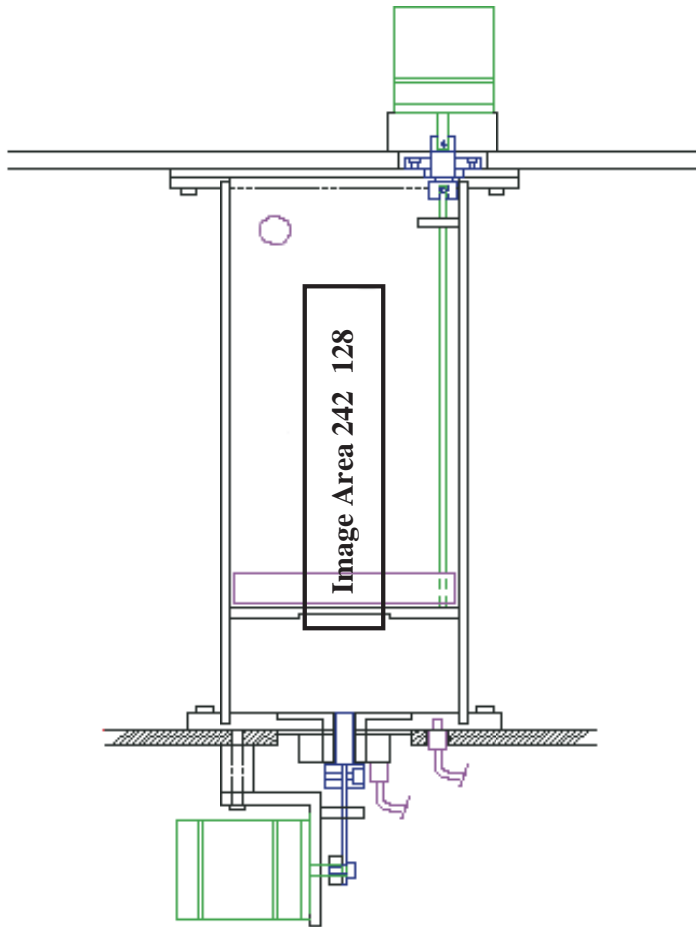
- **CCD camera captured image data**

Experimental Sequence

- Baroswitch turns on Relay A, thermal control begins, payload power is on
- GCD Relay B enables experiment
- Computer initializes
- FAS moved to bottom of FTC
- FTC fills with silicone oil, monitor fluid level, stop when filled to knife edge
- Move FAS to the top of the test cell
- Experiment sequence begins
  - Lower piston
  - Fill cylindrical cavity with PSL
  - Turn off fan
  - Turn on laser
  - Capture five initial images
  - Initiate piston motion, record piston position
  - Start image capture
  - Turn off laser
  - Turn on fan
  - Transfer images to disk
- Run experiment sequence 100 times (approximately 5 hours)
- After 100 experiments completed, lower FAS to bottom of test cell
- Empty all silicone oil from FTC back into reservoir
- Raise FAS halfway and wait for experiment to be turned off

Digital Imaging System

Image Area 242 ⨯ 128

- **256-level grayscale, digitally controlled, CCD camera**
- **Capable of 242⨯753 resolution, subsampled to 242⨯128 to increase capture rate**
- **Varied gain to achieve variety of image data**
- **Three step operation**
  - **Memory allocation**
  - **Image capture**
  - **Image storage**
- **40 separate image files per experiment sequence**

Captured Image Data
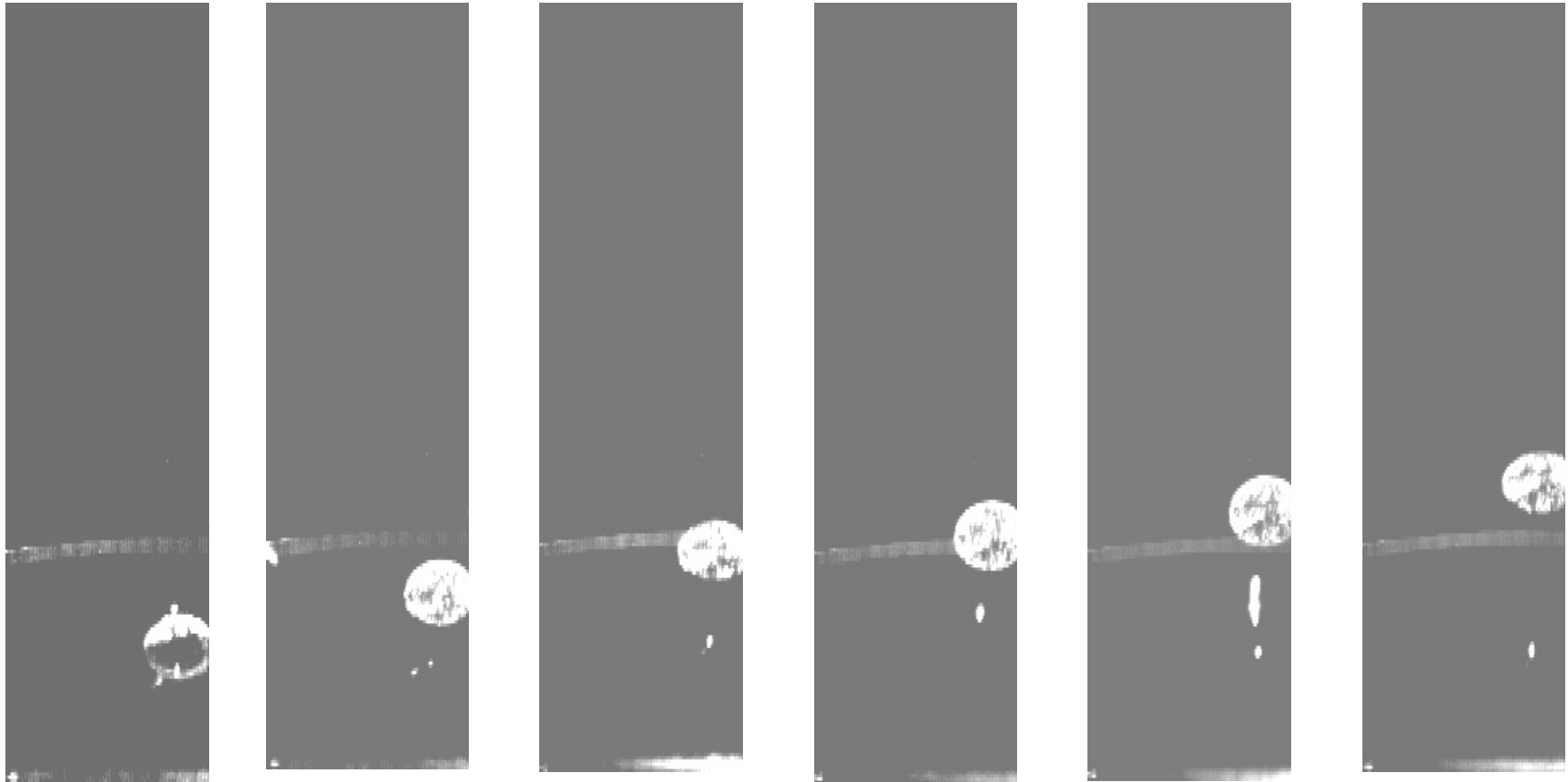
The vortex ring propagates upwards through the interface and forms a droplet. These images were obtained at different times during the motion.

VORTEX Data Product

- **The μg experiments characterized the evolution and interaction of the vortex ring with the fluid–gas interface**

- **Measurements will be made on the captured video images to characterize the interaction and drop-formation processes**

- **Measurements will be compared with numerical simulations and 1-g experiments**

- **Parameters that will be extracted from image data include:**
    - Interface and vortex ring position as a function of time
    - Location and time of interface breakup
    - Size and evolution of the main drop after interface breakup
    - Time, location, and size of satellite drops formed after the interaction
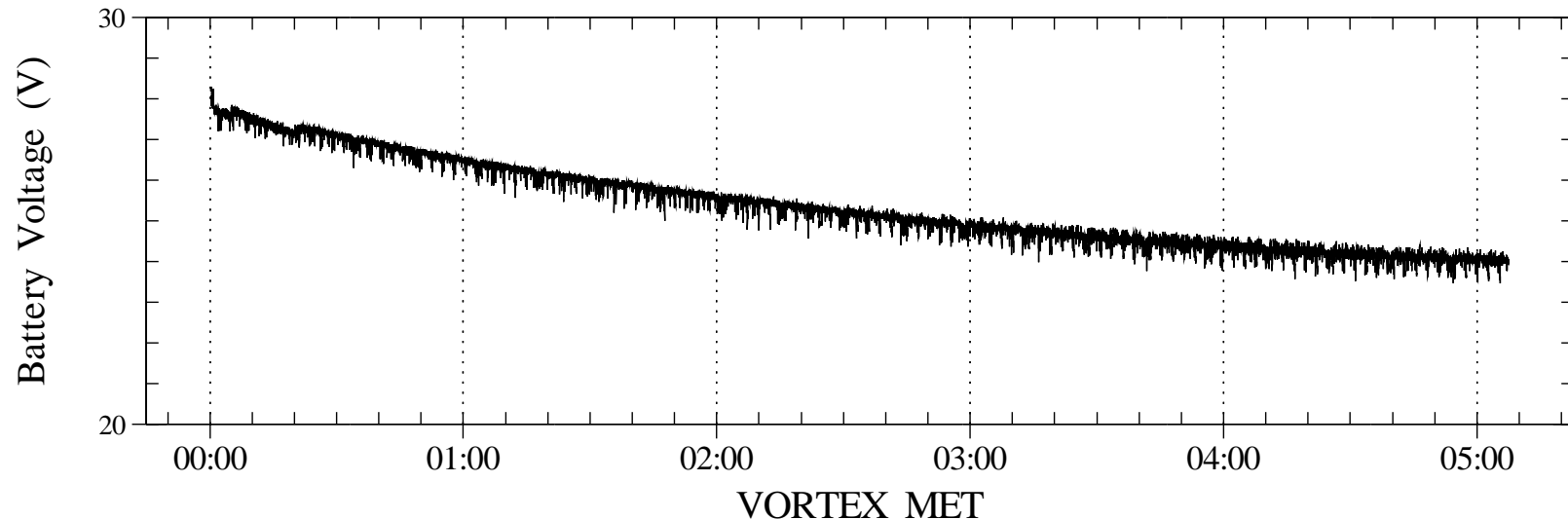
Internal and External Temperatures

VORTEX Temperatures
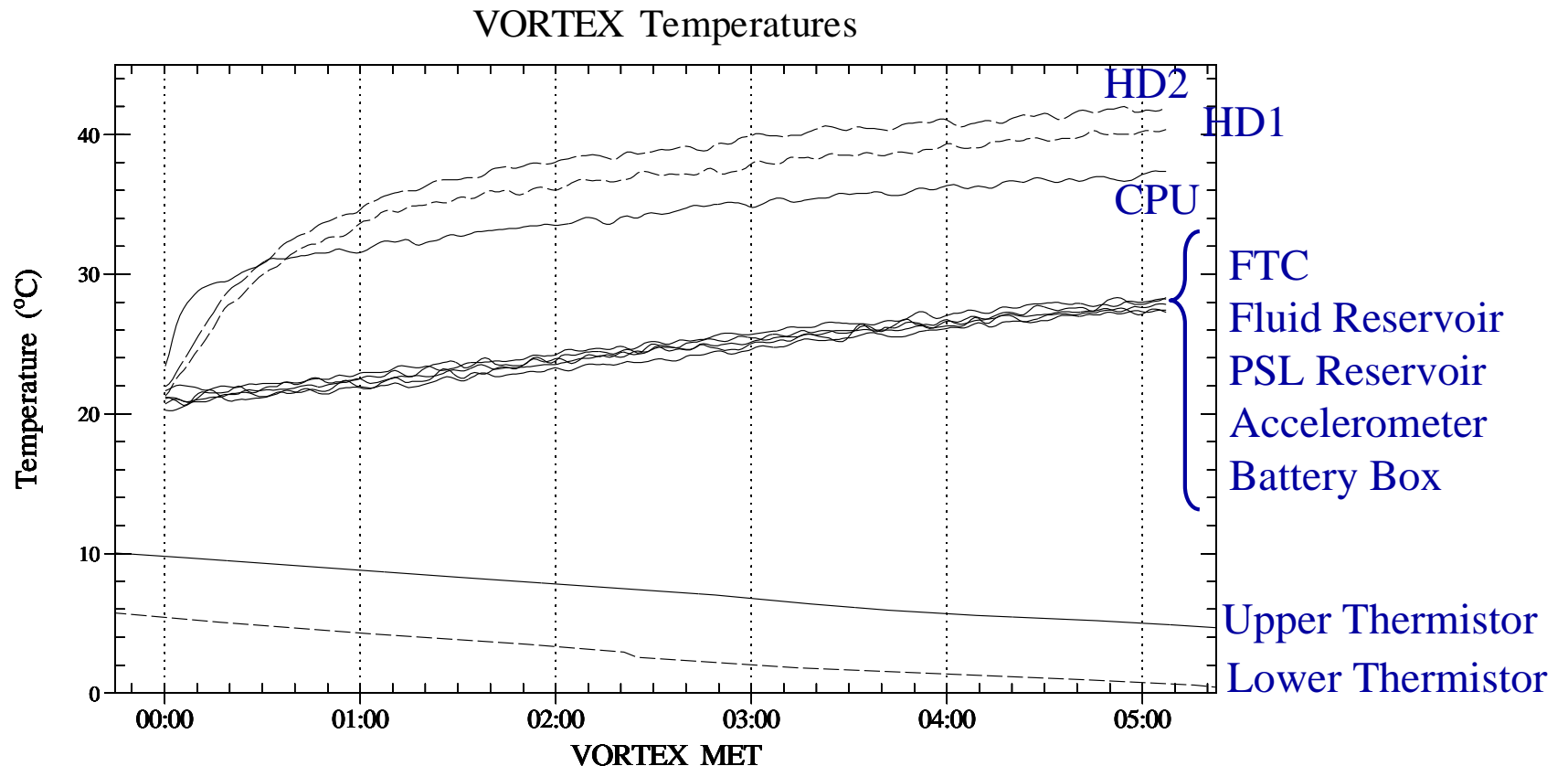
- **During VORTEX mission external temp. never below 0 °C**
- **Hard-drives and computer temperatures highest**
- **Fans adequately mix payload's atmosphere to equalize temps**

Battery Box Voltage
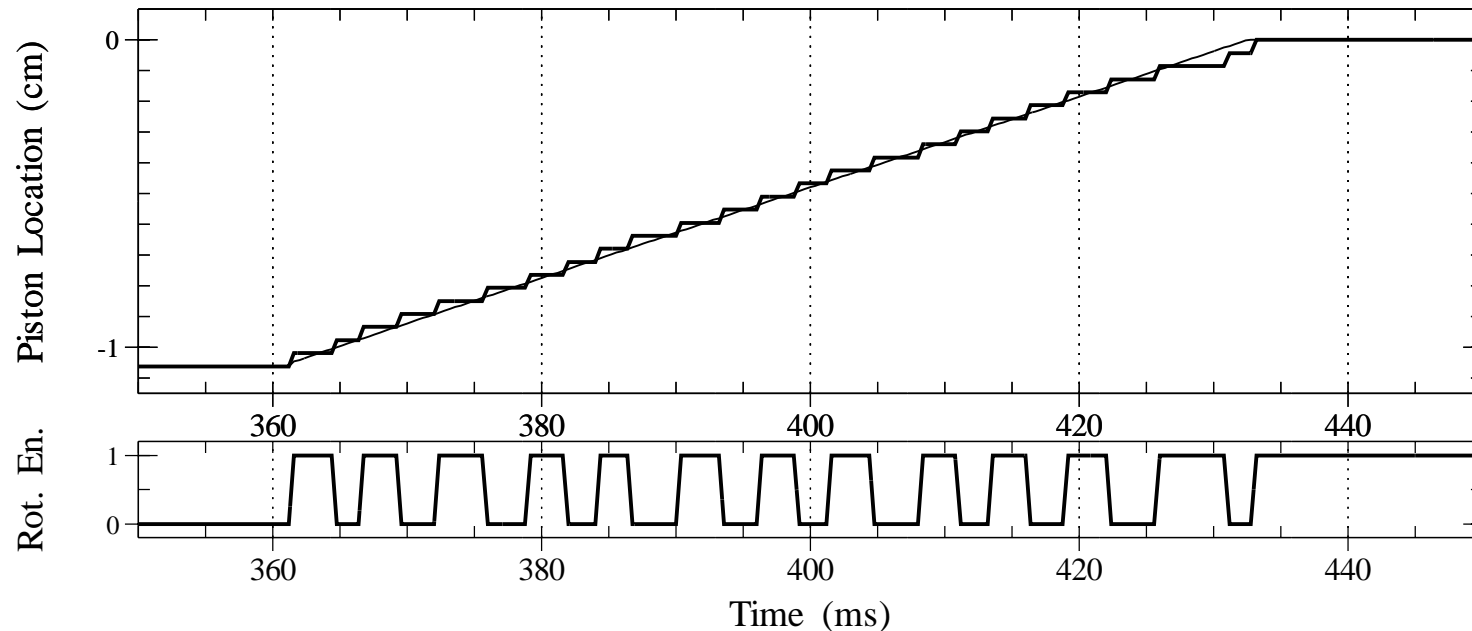
VORTEX Battery Voltage

- **Main battery provided adequate payload power during VORTEX mission**

- **Other bus voltages remained steady throughout mission**

- **Future payloads should add current sensor to measure power delivered**
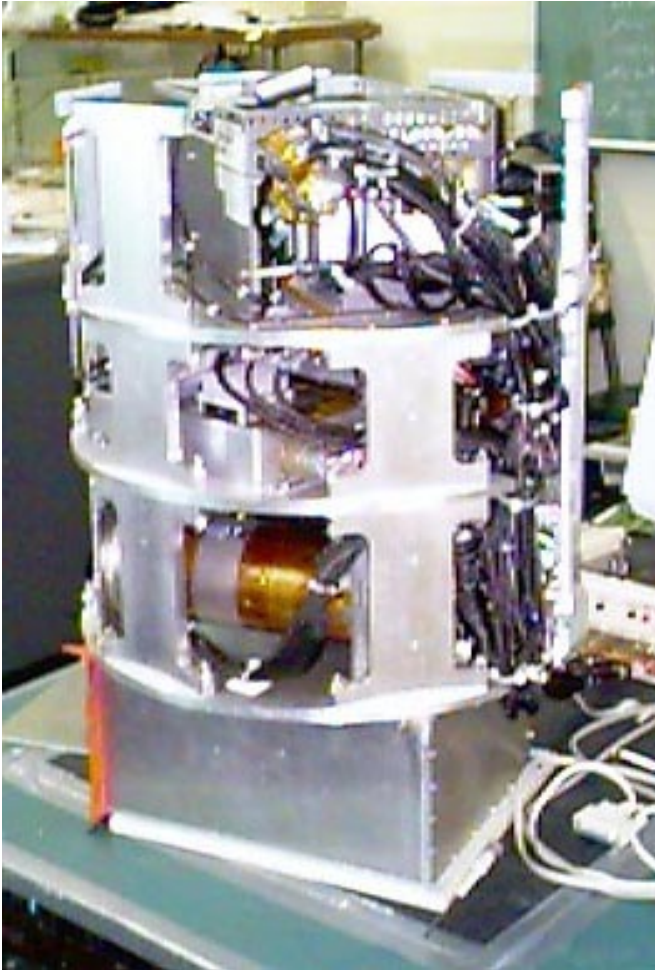
Encoder Data

Piston Location During Vortex Ring Generation

- **Rotary encoder provides TTL-level signal that toggles between high (1) and low (0) every 1.8°**

- **Example shows smoothed piston velocity of 14.75 cm/s**

- **Important for verification of piston speed**

Post-Mortem and Comments

- **Due to cost constraints, most components were commercial off-the-shelf (COTS)**

- **Computer experienced permanent damage during flight, but not before all data was collected**
  - **Possibly consider lower generation processor, *e.g.* 286**
  - **Possibly consider PC/104 architecture in future payloads**

- **Other components performed as designed**

Summary

- **VORTEX studied propagation of a vortex ring through a liquid–gas interface in microgravity**
- **G-093 flew on two Shuttle flights: STS-89 in January 1998 and STS-88 in December 1999**
- **Valuable scientific data captured on STS-88**
- **VORTEX scientific mission lasted 5 hrs, 10 min**
- **More info can be found on the VORTEX Website**
  http://aoss.engin.umich.edu/vortex